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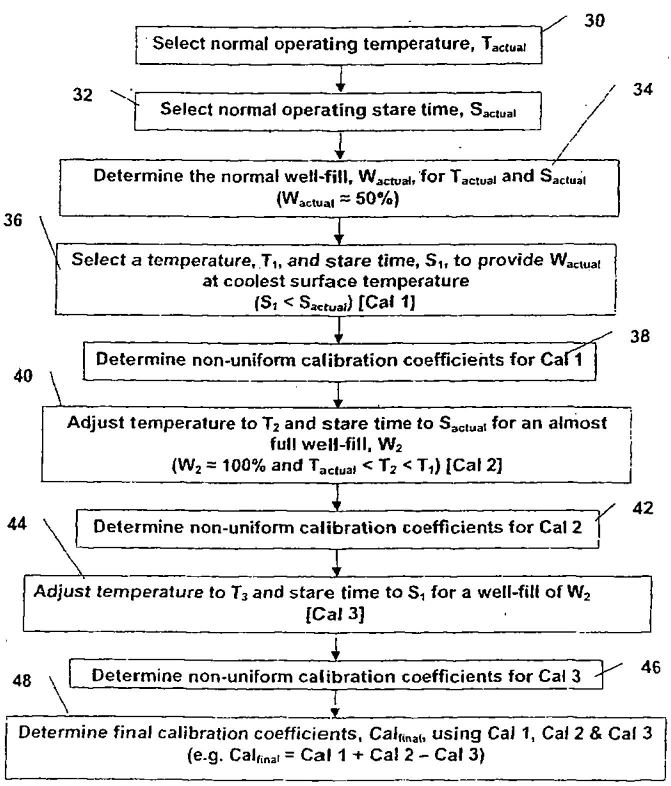

(57) Abstract: Described herein is a method and apparatus for calibrating an infra red camera at elevated temperatures using a reference surface. The method comprises selecting a normal well-fill condition for pixels in the camera in accordance with normal operating temperatures and stare time (30, 32, 34), using the normal well-fill condition to calculate a selected stare time/surface temperature combination for which selected non-uniform calibration coefficients are determined (36, 38), adjusting and re-adjusting the stare time/surface temperature to obtain adjusted and re-adjusted non-uniform calibration coefficients respectively (40, 42, 44, 46), and determining final non-uniform calibration coefficients for the camera using the selected, adjusted and readjusted non-uniform calibration coefficients (48).

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

IMPROVEMENTS IN OR RELATING TO INFRA RED CAMERA CALIBRATION

The present invention relates to improvements in or relating to infra red camera calibration, and is more particularly, although not exclusively, concerned with non-uniformity calibration.

It is known to perform internal two-point non-uniformity calibration in infra red cameras at ambient temperatures above 28°C. However, it has been difficult to achieve such calibration due to the inability to control the thermal reference surface temperature to reach the desired set point for the operating temperature range of the camera based on selected stare time. The desired set point is typically 5°C but the achievable reference surface temperature is approximately ambient temperature less 25°C. This has the disadvantage that, in applications where an infra red camera having a wide field of view is to be used in ambient temperatures equivalent to 55°C, the achievable reference surface temperature is expected to be around 30°C (55-25°C). This is substantially higher than both the desired set point and the specified scene temperatures equivalent to 10°C.

Whilst it is possible to modify the calibration technique so that camera calibration can be carried out using the "best achievable" reference surface temperature, a significant shortfall in the performance of the camera is obtained relative to the performance which would be obtained if the camera calibration is performed using its ideal set point temperature. Moreover, if single-point calibration steps are performed at temperatures which are significantly different from those which are present in a background of a scene, the advantages and benefits of such calibration steps will be substantially lost as a result of the differences between the actual calibration temperatures and the desired calibration temperatures.

It is therefore an object of the present invention to provide a calibration method which provides for the benefits of both single-point and two-point

calibration being substantially recovered whilst using achievable reference surface temperatures rather than ideal reference surface temperatures.

In accordance with one aspect of the present invention, there is provided a method of calibrating an infra red camera using a temperature-adjustable reference surface, the method comprising the steps of:-

a) selecting a stare time/surface temperature combination for the camera;

b) determining non-uniform calibration coefficients for the selected combination;

c) adjusting the stare time/surface temperature combination;

d) determining non-uniform calibration coefficients for the adjusted combination;

e) re-adjusting the stare time/surface temperature combination;

f) determining non-uniform calibration coefficients for the re-adjusted combination; and

g) using the selected, adjusted and re-adjusted non-uniform calibration coefficients to produce final non-uniform calibration coefficients for the camera.

Advantageously, step a) comprises the steps of:-

(i) determining a well-fill as a function of operating scene temperature and stare time; and

(ii) selecting the stare time/surface temperature combination in accordance with the determined well-fill.

Preferably, the well-fill is selected to be approximately 50%, but it will be appreciated that any other suitable well-fill value may be used according to characteristics of the infra red camera being calibrated.

Moreover, step c) comprises the step of:-

(iii) selecting a surface temperature for the operating stare time to produce a further well-fill.

The further well-fill may be selected to be near 100% but again any suitable well-fill value may be used depending on the characteristics of the infra red camera being calibrated.

Step e) may comprise using the selected stare time of step (ii) and the further well-fill to produce the re-adjusted surface temperature.

According to the present invention step g) comprises determining the final non-uniform calibration coefficients in accordance with the sum of the selected and re-adjusted non-uniform calibration coefficients less the adjusted non-uniform calibration coefficients. Naturally, it will be understood that the way the non-uniform calibration coefficients for each stare time/surface temperature combination are used for the final calibration may be varied in accordance with the characteristics of the camera being calibrated.

In accordance with another aspect of the present invention, there is provided apparatus for calibrating an infra red camera, the apparatus comprising:-

a temperature-controlled reference surface, the camera being located within the apparatus to view the reference surface;

control means for controlling the temperature of the reference surface and the stare time of the camera in accordance with predetermined criteria; and

processing means for receiving output signals from the camera in accordance with each stare time/surface temperature combination in accordance with the predetermined criteria, for producing non-uniform calibration coefficients corresponding to each stare time/surface temperature combination, and for determining final non-uniform calibration coefficients for the camera from the non-uniform calibration coefficients determined in accordance with the predetermined criteria.

For a better understanding of the present invention, reference will now be made, by way of example only, to the accompanying drawings in which:-

Figure 1 is a block diagram illustrating calibration apparatus in accordance with the present invention; and

Figure 2 is a flow diagram illustrating the calibration process in accordance with the present invention.

In accordance with the present invention, a method will be described which allows the benefits of both single-point and, by extension, two-point calibrations to be substantially recovered, whilst using achievable reference surface temperatures instead of ideal reference surface temperatures.

Turning initially to Figure 1, a calibration apparatus 10 is shown. The apparatus comprises a reference surface 12 whose temperature is controlled by a temperature control device 14. An infra red detector arrangement 16 which is to be calibrated is positioned so that an infra red detector 18 has the reference surface in its field-of-view. The detector has a cooling unit 20, a processor 22 and a memory unit 26 as is conventional. The processor 22 provides an output signal 24 indicative of radiation incident on the detector 18.

The calibration apparatus 10 also comprises a controller 28 which is connected to receive the output signal 24 from the detector arrangement 16 and to provide control signals for the temperature control device 14 and the memory unit 26.

When an infra red detector 18 is to be calibrated, connections as described above are made so that for each temperature of the reference surface 12, the output signal 24 is compared with the temperature in the controller 28. This provides calibration coefficients for a particular temperature which are stored in memory unit 26 for use when the detector 18 is in normal operation.

In accordance with the present invention, it is assumed that the principal sources of error which must be calibrated are pixel by pixel variations in offset

and scale factor. It is possible to calibrate for offset and scale factor using a two-point, or possibly three-point, calibration technique.

It will readily be understood that an infra red detector or camera comprises an array of pixels which collects the incident radiation, and that each pixel tends to have its own characteristics which are defined as an offset value and scale factor.

For an ideal two-point calibration, the temperature of the reference surface is first controlled to have a value close to, or at, the equivalent scene temperature operating point. A selected stare time is chosen and data is collected from the detector over the selected stare time. It will be appreciated that the detector receives a de-focussed image of the reference surface over the stare time. The collected data is processed to determine correction values, for example, offset values of the pixels, at the equivalent scene temperature. The temperature of the reference surface is then altered to be different from the first temperature, that is, different from the equivalent scene temperature.

It will readily be understood that data at the first temperature is ideally used to calibrate offsets and sensitivities under the same radiance and stare time conditions under which the detector will be used and gives the same "well-fill" conditions that the detector will see from the scene. By the term "well-fill" is meant the amount of charge developed by each pixel in response to the incident radiation.

However, as it is not possible to reduce the temperature of the reference surface to provide the required radiance value, the present invention provides for a selection of a combination of stare time and reference surface temperature which provides an equivalent well-fill. This requires a reduction in stare time to offset the increased spectral radiance at higher reference surface temperatures. The relationship is dictated by Planck's law and is non-linear.

The selection of a suitable combination of stare time and reference surface temperature allows calibration at an equivalent well-fill to be performed. However, the adequacy of such a calibration depends on the effects of non-uniformity relating to changes in stare time either to be negligible or to be further

calibrated out. Generally, it should be assumed that non-uniformity effects relating to changes in stare time are not negligible and need to be estimated. This can be achieved by performing two or more further calibrations at combinations of stare time and reference surface temperature which give equivalent well-fill values to one another.

In accordance with the present invention, a three-step calibration process is provided which essentially comprises three combinations of stare time and reference surface temperature to allow pixel offsets and scale factor values to be estimated for the well-fill and stare time combination which will be used in practice. This is illustrated in Figure 2.

Suppose an infra red detector or imager is to be used with a stare time, S_{actual}, (step 32) and a scene temperature, T_{actual}, (step 30) to give a well-fill of W_{actual}, then

$$W_{actual} = \text{function}\ (T_{actual}, S_{actual})$$

where W_{actual} has a typical value of 50% (step 34).

The first non-uniform calibration step, Cal 1, is performed at T_1 and S_1 to give a well-fill W_{actual} at the coolest possible reference surface temperature (step 36). This means that S_1 is a shorter stare time than that used in practice, S_{actual}.

The compensation (that is, the non-uniform calibration coefficients (step 38)) obtained is correct in terms of well-fill, but is in error if the detector has non-uniform sensitivities to the change in stare time from S_{actual} to S_1. These sensitivities can be measured and compensated by two further calibration steps.

The second calibration step, Cal 2, is performed at an intermediate surface temperature of T_2 and at a stare time of S_{actual}. This gives a well-fill of W_2 which is, for example, near 100% well-fill (step 40). The non-uniform calibration coefficients are determined in step 42.

The third calibration step, Cal 3, is performed at a surface temperature of T_3 using a stare time of S_1 to give a well-fill of W_2 (step 44) and the non-uniform calibration coefficients are determined in step 46.

It will be appreciated that each of the second and third calibration steps provides non-uniform calibration coefficients, and these non-uniform calibration coefficients can be used to determine if any adjustment is needed for the first non-uniform calibration step. In this example, the difference between the second and third non-uniform calibration coefficients is used to effect adjustment of the first non-uniform calibration (step 48). However, it will be understood that the second and third calibration coefficients may be used in different ways to achieve adjustment of the first non-uniform calibration coefficient.

It is expected that all three calibration steps are performed at achievable temperatures and stare times.

The final non-uniform calibration coefficients, $coeff_{final}$, can be expressed as:-

$$coeff_{final} = coeff_{Cal1} + coeff_{Cal3} - coeff_{Cal2}$$

The method of the present invention is very simple in practice, although some new surface temperature set points and corresponding stare times need to be calculated and tested to achieve equivalent well-fills. Moreover, the non-uniform calibration coefficients from three tests need to combined as described above.

The method of the present invention has the advantage that hotter surface temperatures can be utilised during calibration than is conventionally required.

CLAIMS

1. A method of calibrating an infra red camera using a temperature-adjustable reference surface, the method comprising the steps of:-

a) selecting a stare time/surface temperature combination for the camera;

b) determining non-uniform calibration coefficients for the selected combination;

c) adjusting the stare time/surface temperature combination;

d) determining non-uniform calibration coefficients for the adjusted combination;

e) re-adjusting the stare time/surface temperature combination;

f) determining non-uniform calibration coefficients for the re-adjusted combination; and

g) using the selected, adjusted and re-adjusted non-uniform calibration coefficients to produce final non-uniform calibration coefficients for the camera.

2. A method according to claim 1, wherein step a) comprises the steps of:-

(i) determining a well-fill as a function of operating scene temperature and stare time; and

(ii) selecting the stare time/surface temperature combination in accordance with the determined well-fill.

3. A method according to claim 2, wherein step (i) comprises selecting a well-fill of approximately 50%.

4. A method according to claim 2 or 3, wherein step c) comprises the step of:-

(iv) selecting a surface temperature for the operating stare time to produce a further well-fill.

5. A method according to claim 4, wherein the further well-fill is selected to be near 100%.

6. A method according to claim 4 or 5, wherein step e) comprises the step of:-

(iv) using the selected stare time of step (ii) and the further well-fill to produce the re-adjusted surface temperature.

7. A method according to any one of the preceding claims, wherein step g) comprises determining the final non-uniform calibration coefficients in accordance with the sum of the selected and re-adjusted non-uniform calibration coefficients less the adjusted non-uniform calibration coefficients.

8. Apparatus for calibrating an infra red camera, the apparatus comprising:-

a temperature-controlled reference surface, the camera being located within the apparatus to view the reference surface;

control means for controlling the temperature of the reference surface and the stare time of the camera in accordance with predetermined criteria; and

processing means for receiving output signals from the camera in accordance with each stare time/surface temperature combination in accordance with the predetermined criteria, for producing non-uniform calibration coefficients corresponding to each stare time/surface temperature combination, and for determining final non-uniform calibration coefficients for the camera from the non-uniform calibration coefficients determined in accordance with the predetermined criteria.

9. A method of calibrating an infra red camera using a temperature-adjustable reference surface substantially as hereinbefore described with reference to the accompanying drawings.

10. Apparatus for calibrating an infra red camera substantially as hereinbefore described with reference to Figure 1 of the accompanying drawings.

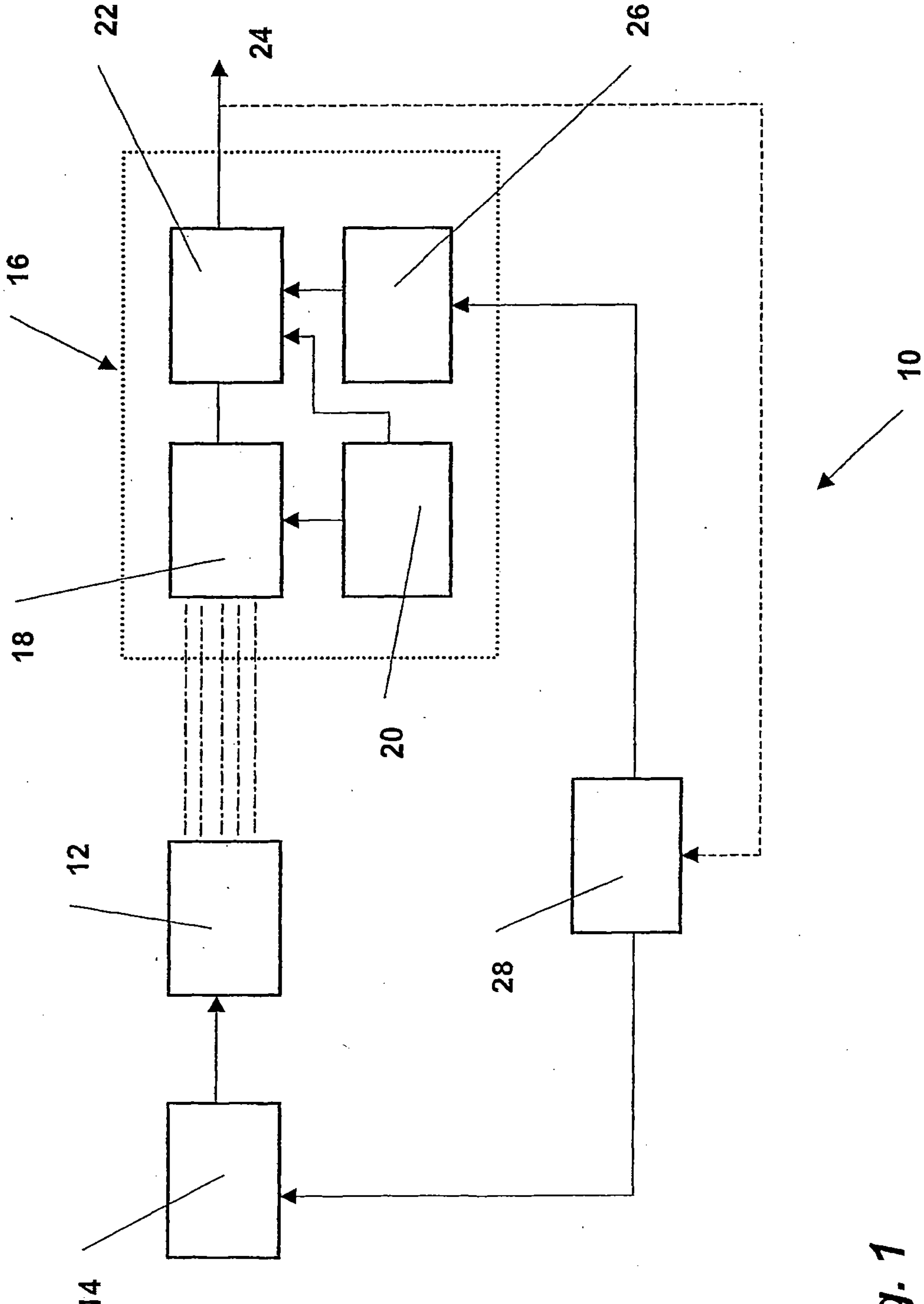

Fig. 1

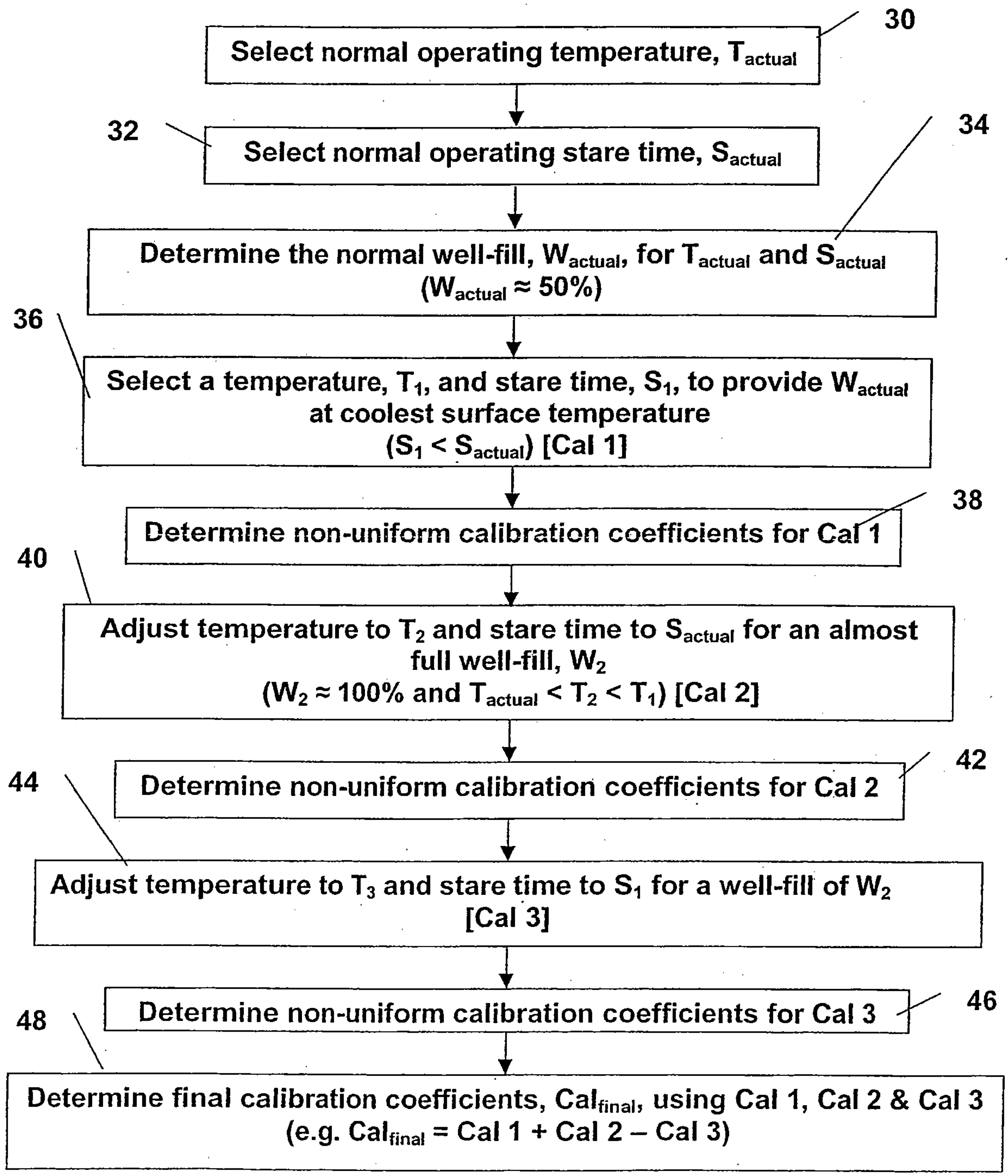
30
Select normal operating temperature, T_{actual}
32
Select normal operating stare time, S_{actual}
34
Determine the normal well-fill, W_{actual}, for T_{actual} and S_{actual}
($W_{actual} \approx 50\%$)
36
Select a temperature, T_1, and stare time, S_1, to provide W_{actual} at coolest surface temperature
($S_1 < S_{actual}$) [Cal 1]
38
Determine non-uniform calibration coefficients for Cal 1
40
Adjust temperature to T_2 and stare time to S_{actual} for an almost full well-fill, W_2
($W_2 \approx 100\%$ and $T_{actual} < T_2 < T_1$) [Cal 2]
42
Determine non-uniform calibration coefficients for Cal 2
44
Adjust temperature to T_3 and stare time to S_1 for a well-fill of W_2
[Cal 3]
46
Determine non-uniform calibration coefficients for Cal 3
48
Determine final calibration coefficients, Cal_{final}, using Cal 1, Cal 2 & Cal 3
(e.g. Cal_{final} = Cal 1 + Cal 2 – Cal 3)

Fig. 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 03/00923

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N5/33 H04N5/217

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6 127 679 A (ELLIOTT CHARLES T ET AL) 3 October 2000 (2000-10-03) column 3, line 10 - line 13 column 5, line 7 - line 15 column 6, line 57 -column 8, line 31 ---	1,8-10
A	WO 00 52435 A (RAYTHEON CO) 8 September 2000 (2000-09-08) claim 1 -----	1,8-10

[ ] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
21 May 2003	28/05/2003

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Wentzel, J

INTERNATIONAL SEARCH REPORT

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